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USAF EHL-M

AN ENVIRONMENTAL EVALUATION OF ACID SCRUBBERS
Building 628, McClellan AFB CA

By

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August 1975

U S A F ENVIRONMENTAL HEALTH LABORATORY

McCLELLAN AFB, CA. 95652

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ABSTRACT

An environmental evaluation was conducted of an operation in which nitric, perchloric and hydrochloric acid vapors and aerosols are generated. The evaluation was requested to determine why a visible white plume existed at the exhaust of a wet scrubber. The white plume was formed regardless of meteorological conditions when acid vapors and aerosols were generated. The evaluation included a scrubber efficiency study, an environmental assessment and an air pollution regulation compliance test.

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1. Introduction:

Laboratory procedures, conducted by the 1155th Technical Operations Squadron in Building 628, McClellan AFB, generate acid vapors and aerosols in sufficient quantity to require their control prior to release of the exhaust to the outside atmosphere. Control equipment (wet scrubbers) presently in place does not remove all of the acid vapors and aerosols. A white plume formed in the fume hood remains visible in the scrubber's exhaust gas. The white plume is visible regardless of atmospheric conditions and is characteristic of acid plumes (Ref. 1). The plume is not formed when only room air is being scrubbed.

DEE, McClellan AFB, through AFLC/SGB, requested USAFEHL-M to conduct a study to determine: (a) collection efficiency of the present control equipment, (b) the nature and quantity of pollution being released to the atmosphere, and (c) the need for additional control and how it can be obtained.

2. Process Description:

Acid vapors and aerosols are generated during a laboratory procedure in which a cellulose material $(C_6H_{10}O_5)_2$ is digested with acid. Nitric acid (90% HNO_3), perchloric acid (70% $HClO_4$) and the cellulose material are combined in a beaker and the mixture is brought to a boil. The mixture boils at ~ 120° C until the excess HNO_3 is evaporated and then boils at 200 °C until the $HClO_4$ is evaporated. Hydrochloric acid (37% HCl) is added to the dry beaker and boiled at ~ 140 °C to dryness. The HCl procedure is repeated three times.

Chemical reactions during cellulose digestion are: (Ref. 2).

a. $6HNO_3 + (C_6H_{10}O_5)_2 \xrightarrow{\Delta} C_{12}H_{14}(ONO_2)_6O_4 + 6H_2O$

b. $6HClO_4 + C_{12}H_{14}(ONO_2)_6O_4 \xrightarrow{\Delta} 12CO_2 + 6HNO_3 + 6HCl + 4H_2O$

c. $HCl + \text{Residue} \xrightarrow{\Delta} HCl + \text{Negligible Products}$

The mass (volume) of digestion products generated by the chemical reactions is small compared to the acid vapors and aerosols generated since only 60 to 100 grams of cellulose are digested. The major contaminants are the acid vapors and aerosols. Less than 2.5% of the acids are decomposed to other products such as NO_x and Cl (Ref. 2). The maximum acid vapor and aerosol mass loadings to each scrubber are: (a) 204

gms/min HNO_3 , (b) 104 gms/min $HClO_4$ and 192 gms/min HCl. These mass loadings occur very infrequently. The digestion procedure itself occurs infrequently, less than 2 hours per week on the average (Ref. 3).

3. Scrubber Description:

Two different makes of scrubbers are presently in place (19 scrubbers). Fourteen scrubbers are old, worn out, and must be replaced. The remaining five scrubbers are relatively new and can be maintained. Only the newer scrubber make was evaluated.

The newer scrubber is manufactured by the American Air Filter Company, Inc. (AAF). The equipment is identified by the acronym COLAG meaning Contact of Liquid and Gas. AAF's catalog which describes this unit is included as Appendix I. The scrubber consists of a stack of three size 35 stages (Figure 1). Air enters each stage from below and is distributed by a perforated plate. Water supplied to the plate is entrained upward to a reaction pad. Liquid droplets which pass through the pad are trapped by sloped eliminator pads and flow to drainage channels, then out of the unit. Each scrubber serves two fume hoods (Figure 2). The mass loadings given above are for both hoods in operation.

The unit is designed to operate at 1900 to 3500 CFM air flow, 0.37 GPM water flow per stage and 4 to 13 inches of water gauge static pressure (Ref. 4). The unit when tested was operating at 2042 CFM air flow and 0.85 GPM water flow per stage. Static pressure could not be measured without damaging the unit.

4. Scrubber Efficiency:

Collection efficiencies were determined for nitric and perchloric acid vapor/aerosol under normal operating conditions. Collection efficiencies were 74 and 75% respectively for nitric acid loadings of 68.8 and 189.9 gms/min and 61% for a perchloric acid loading of 40.6 gms/min. The last loadings were chosen to best represent the normal operation.

5. Discussion

Thermally produced nitric acid aerosol in this situation has a mass median diameter (MMD) of 1.0 micrometer (μm) (Ref. 5). No reference could be found for perchloric and hydrochloric acid aerosol produced thermally.

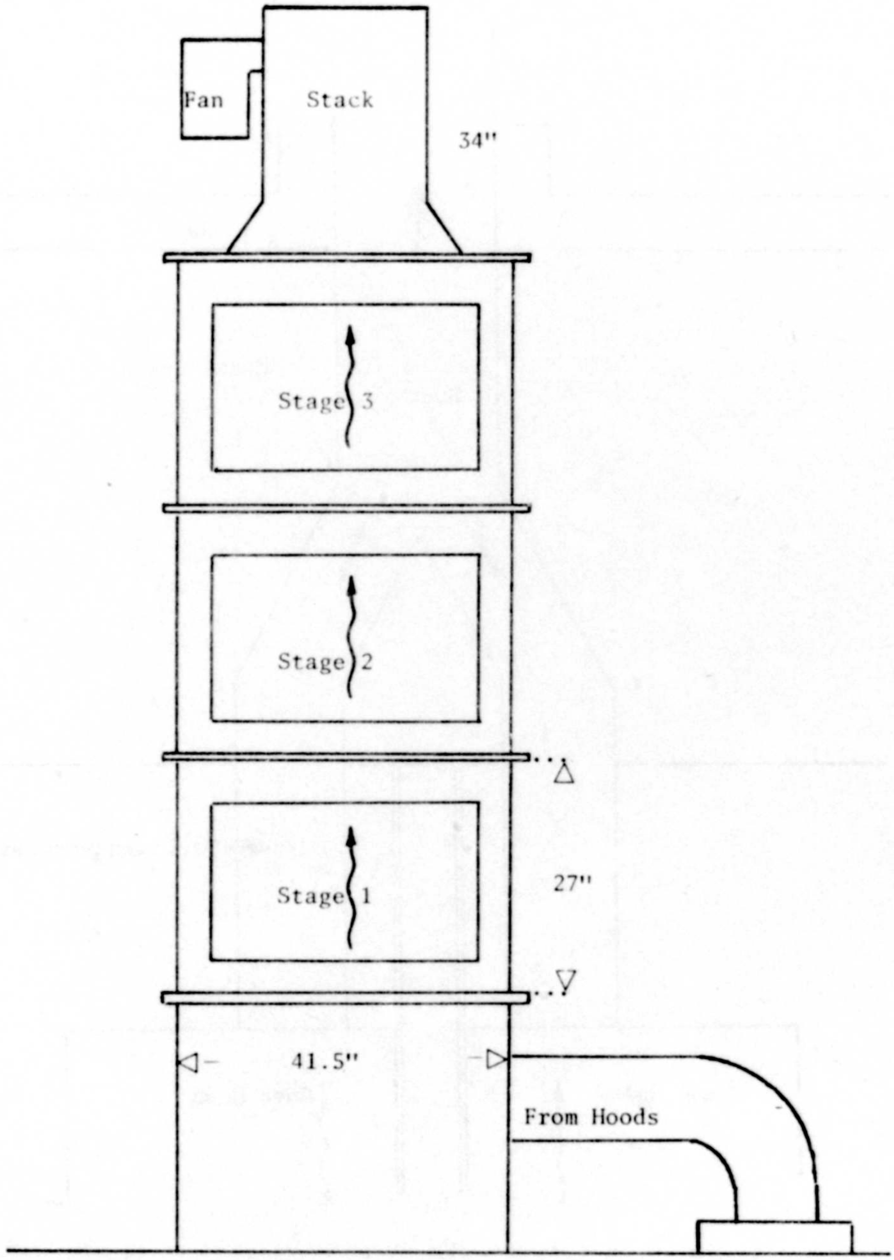

Figure 1: AAF COLAG Scrubber, Bldg 628, McClellan AFB CA AO July 75

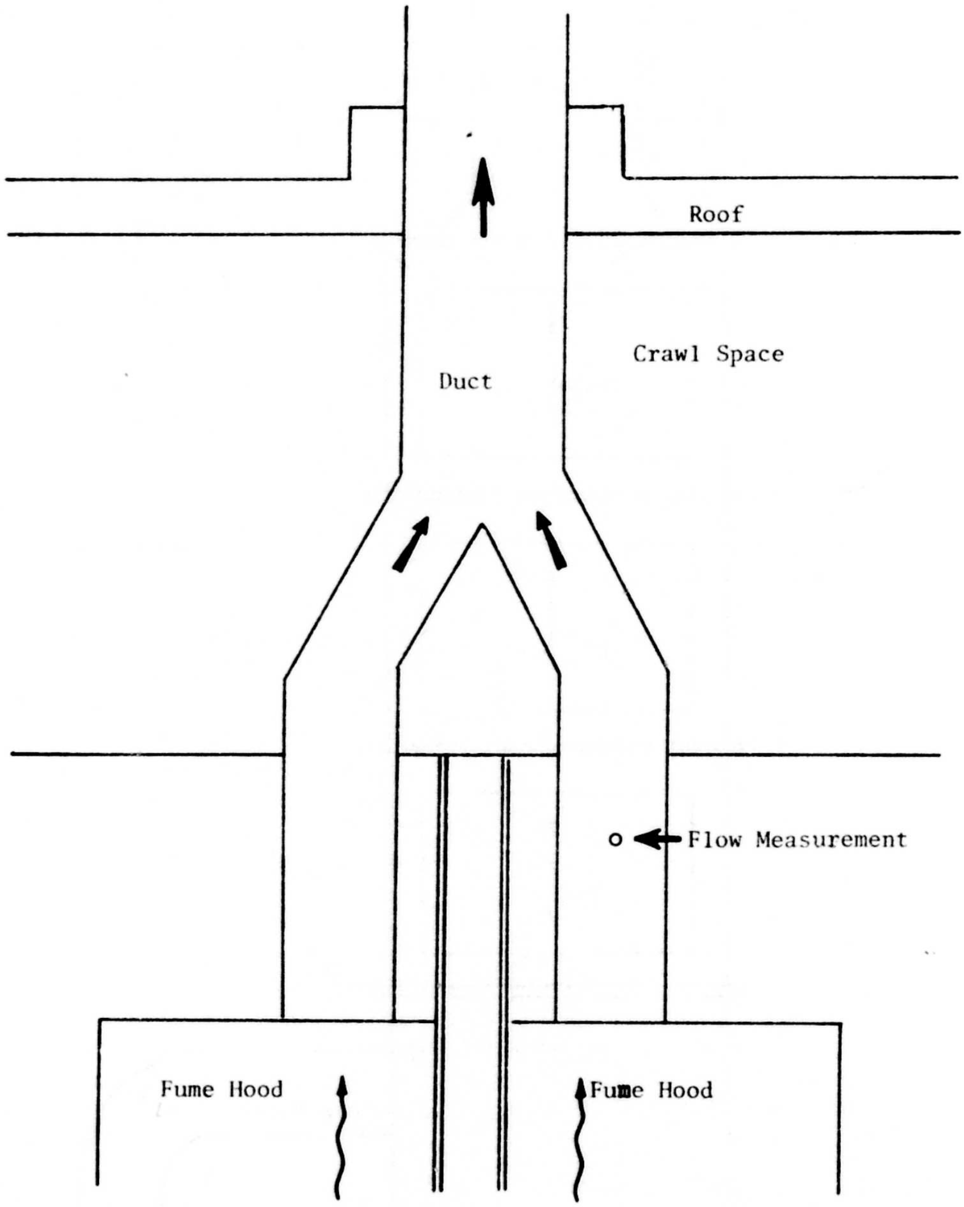

Figure 2: Scrubber Arrangement, Bldg 628, McClellan AFB CA

Cleaning air that is contaminated with particles having a 1 μm MMD is very difficult, especially with low energy scrubbers such as the one under question. Ellison (Ref. 6) studied eight types of wet scrubbers and found collection efficiencies ranging from 42 to 80% for 1 μm particles in low energy scrubbers. High energy scrubbers, venturi and wet dynamic, had much higher efficiencies (91 to 98%) for 1 μm particles.

The AAF COLAG unit is a low energy scrubber but one of the best in the category. It has many characteristics similar to a flooded bed scrubber for which Ellison found a maximum collection efficiency of 80% for 1 μm particles. Our collection efficiency tests show that the COLAG unit is functioning as well as can be expected for this particular application. AAF's catalog (page 9) shows an expected collection efficiency of 78% for 1 μm particles and one stage.

Collection efficiency for the acid vapor/aerosol can be improved significantly, but it will require a high energy wet scrubber, of which many types are available, or electrostatic precipitation.

Types of wet scrubbers commonly used for this type operation are: (a) venturi, (b) wet dynamic, (c) packed tower and (d) wet fabric filtration (Ref. 2).

Electrostatic precipitation requires a high initial capital expenditure and intensive maintenance, especially in an acid environment. This method of control is not indicated for this small size operation.

Another approach commonly used in aerosol collection is physical growth of the aerosol to a much larger size and then collection by conventional low energy wet scrubbing. The method of aerosol growth depends on particle properties. In the case of hygroscopic acid particles, growth can be accomplished by humidification. As noted later in the report aerosol growth appeared to be occurring in the COLAG unit by humidification, but sufficient growth did not occur to improve collection efficiency. The second and third stages were added probably to effect particle growth and increased efficiency.

In addressing the question of whether additional collection efficiency is needed, three aspects were considered: (a) environmental nuisance or annoyance (b) environmental injury or detriment and (c) violation of air quality rules and regulations.

a. Environmental Nuisance or Annoyance:

No complaints of nuisance or annoyance have been registered against this operation since the present scrubbers have been installed (Ref. 7). In addition to the visible plume, other properties (in the absence of environmental injury) of the scrubber exhaust that would cause a nuisance or annoyance would be smell and/or mucous membrane irritation to exposed individuals. The exhaust is released ~40 feet above ground level and the area around Building 628 is parking space. The exhaust is diluted many times before it reaches any occupied area or an area where persons spend more than a few minutes in any given day. An estimate of the actual dilution at the closest location for exposure is impossible. One approach is to calculate the maximum expected acid concentration in the scrubber exhaust and determine the dilution required to lower the concentration to an acceptable level. Using 75% collection efficiency for HNO_3 and HCl (assumed) and 61% for $HClO_4$, and using the maximum loadings to the scrubber, the exhaust would contain ~2400 mg/M^3 at the stack. As a reference point, the allowable exposure of workers to nitric acid vapor/aerosol is 10 mg/M^3 for 15 minutes and 5 mg/M^3 for an 8 hour/day exposure (Ref. 8). A dilution of 240 to 1 would lower the concentration to an acceptable level for 15 minutes of worker exposure. A dilution factor of 240 occurs rapidly in a turbulent atmosphere. Another approach is to estimate ground level concentration during stable (minimal turbulence) atmospheric conditions. Using a stack height of 12.2 meters, an acid mass flow of 2.39 gms/sec, F stability (lowest diffusion) and a wind speed 4 meters/second the maximum ground level concentration (470 meters downwind of the stack) is calculated to be ~0.4 to 0.5 mg/M^3, a concentration well below the acceptable 8 hour per day exposure for workers.

b. Environmental Injury or Detriment:

The area surrounding Building 628 as well as the roof of the building was closely inspected for evidence of corrosion that might have been caused by acid emissions. No evidence was found even in the immediate area of the scrubbers. The scrubbers themselves showed signs of corrosion as would be expected but it was not excessive. No evidence of environmental injury or detriment was found in the area adjacent to the building.

c. Violation of Emission Standards:

An evaluation of the digestion procedure as it relates to Federal, State and Local emission regulations was conducted with assistance from the County of Sacramento Air Pollution Control District. They

stated that due to the type (laboratory) and intermittent nature of the operation the only State regulation that applied is the State of California Code 24242 which restricts plume opacity ... "A person shall not discharge into the atmosphere from any single source of emission whatsoever any air contaminant for a period or periods aggregating more than three minutes in any one hour which is: (a) as dark or darker in shade as that designated as No 2 on the Ringelmann Chart, as published by the US Bureau of Mines, or (b) of such opacity as to obscure an observer's view to a degree equal to or greater than does smoke described in subsection (a) of this section." The white plume was observed on five occasions during maximum activity. Plume opacity did not equal or exceed 40% (No 2 on the Ringelmann scale).

Further, the County of Sacramento as the enforcement agency for the State of California in the county has an "Expections" rule that applies to this activity. Rule 30, Air Pollution Control District Rules and Regulations states, ..."Exceptions. Provisions shall not apply to any activity which is for the purpose of investigation and

a. The Air Pollution Control Officer has granted a permit to conduct said activity, with conditions of said activity specified therein; and

b. The terms of said conditions are met; and

c. The Health Officer of Sacramento County has been consulted and has concurred with such permit and the conditions contained therein; and

d. Said activity does not result in violation of any ambient air quality standard set by the California Air Resources Board or the Federal Environmental Protection Agency."

The cellulose digestion procedure is an investigative procedure that does come under the provisions of Rule 30 and the activity does not violate any ambient air quality standard.

6. Conclusions:

a. Collection efficiency of the AAF COLAG size 35 (75% for HNO_3 and 61% for $HClO_4$) is, for this application, as good as can be expected.

b. During the period of greatest activity, the scrubber exhaust

will contain ~ 2400 mg/M ^{3} (2.39 gms/sec) acid vapors and aerosols. This emission will not last for more than an average of two hours per week.

c. Additional collection efficiency can be obtained but not with low energy wet scrubbers. High energy wet scrubbers (venturi, wet dynamic, wet fabric filtrations, etc.) must be used for improved efficiency.

d. Additional collection efficiency does not seem warranted from an environmental standpoint. No environmental damage or detriment is occurring, complaints of nuisance or annoyance have not been registered and the operation is investigative in nature and falls under the provisions of Rule 30, Exceptions. It is unlikely that a violation of air pollution regulations will occur.

7. Recommendations:

a. From an environmental standpoint, the AAF COLAG units should be maintained as is.

b. In the event that a violation of air pollution regulations does occur, a longer period of time should be used for the digestion procedure, thus decreasing the density of aerosol and consequently plume opacity. This procedure would not be considered illegal circumvention.

c. Specifications for replacement scrubbers should contain:

(1) A through discussion of the cellulose digestion procedure.

(2) A performance bond (installer or manufacturer) requirement.

(3) A pilot plant study requirement.

d. The Air Force should conduct acceptance tests.

e. This evaluation was not concerned with operating costs, maintenance problems, etc. The user (1155th TOS) and Civil Engineering should consider these aspects of the operation prior to any decision to replace them.

8. Apparatus and Materials:

Acids were absorbed in doubly distilled, deionized water. A series of four Greenburg-Smith impingers (Figure 3) was used. The first three impingers (fritted insert) each contained 250 ml of absorption

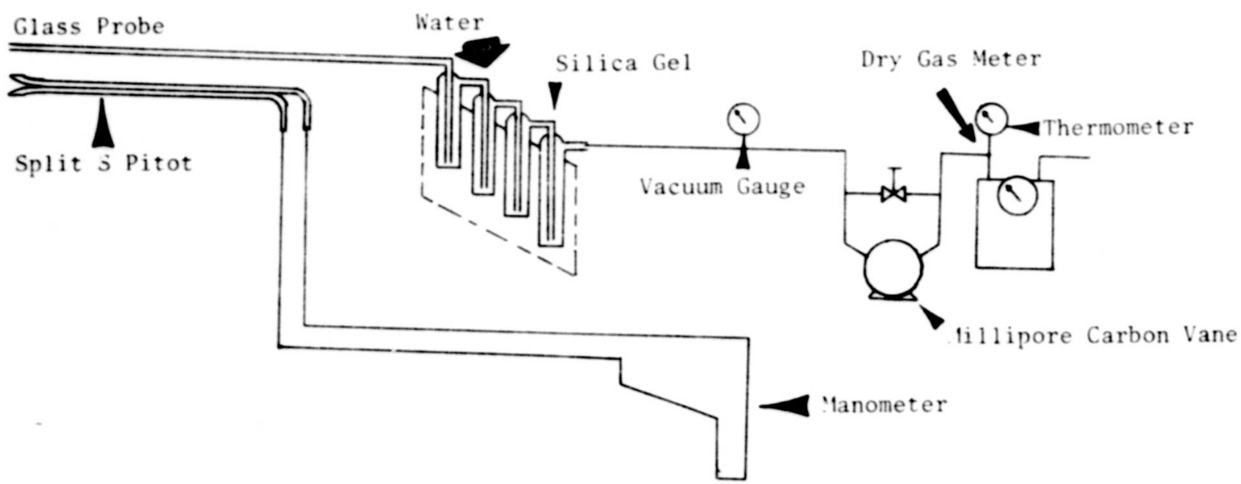

Figure 3: Sampling Train For Acid

medium (water). The last impinger contained silica gel to dry the sample before it entered the pump and dry gas meter. The volume flow rate was measured with a dry gas meter (with temperature sensor) calibrated to a wet test meter.

9. Procedures:

Ideally, acid mist (aerosol) should be sampled isokinetically from a representative cross-section of the stack, preferably according to the EPA Method 8 - Determination of Sulfuric Acid Mist and Sulfur Dioxide Emissions from Stationary Sources. In this particular case, the EPA Method 8 procedures could not be strictly adhered to without expensive modifications to the stack. Therefore, the procedures were modified, and to verify accuracy of data, a material balance of acid evaporated versus acid found in the scrubber water plus that found in the scrubber exhaust gases was performed.

One point sampling was conducted at 6 inches from the inside wall of the 20 inch diameter stack. Since the sampling point was located only one diameter above the fan, no attempt was made to sample isokinetically, instead the largest sample size possible was obtained. The sampling rate was generally 200 to 300% of isokinetic flow, based upon calculated stack velocity as explained later.

Each tests consisted of two samples. One sample was taken when acid was being scrubbed and another identical sample was taken when only room air was being scrubbed (blank). The blank sample was used to obtain the background level of contaminants. The background level was subtracted from the sample to give the true level.

The solution in each impinger was analyzed individually. This was done to evaluate the possibility of bleeding (movement) of acid from one impinger to the next and/or the breakthrough of acid to and through the last impinger.

When nitric acid was sampled the impinger solution was analyzed for nitrate (NO_3^-) and nitrite (NO_2^-).

When perchloric acid was sampled the impinger solution was analyzed for perchlorates (ClO_4^-). Analysis was done by the specific ion electrode method.

Sampling was conducted for 20 minutes. The sampling rate ranged from 0.65 to 1 cubic foot per minute (CFM).

The volume of gas scrubbed could not be measured at the scrubber exhaust due to turbulence. Instead, the flow through one fume hood duct (Figure 2) was measured (six point pitot traverse) and the value multiplied by two. Both fume hoods and the connecting ducts were identical and the assumption that flows in each were equal seemed justified.

To establish a known acid vapor and aerosol concentration, acid was placed in beakers and boiled until a preselected volume of acid remained in the beakers. At this point, sampling was begun and continued for 20 minutes. At the end of sampling, the beakers were removed from the heat (they were near dryness) and the volumes of acid lost during sampling were measured. The volumes lost were converted to mass (specific gravity) and the mass was multiplied by the percentage of acid to arrive at the mass of acid lost. Since 90% nitric acid was used, the loss rate of nitric acid (gms/min) was greater in the early phase of boiling due to azeotrope formation at 70% acid/30% water. To avoid an excessive error in calculating the mass of acid loss, the beakers were boiled to near dryness so that 90% of the total mass lost was acid.

Scrubber water samples were taken each five minutes during sampling. Each individual stage could not be sampled, just the combined drainage from all three stages. It would have been interesting to test each stage for its efficiency. The scrubber water samples were analyzed in the same manner as the impinger solution. Blanks were taken as explained earlier.

10. Data and Discussion:

Collection efficiencies and scrubber operating parameters are presented in Table I. Collection efficiency for nitric acid did not change noticably with an increase in loading of 300%. The lesser collection efficiency for perchloric acid was probably due to the formation of smaller particles upon cooling of the perchloric acid vapor. Perchloric acid, due to its higher boiler point, condenses more readily than nitric acid.

A mass balance is presented in Table II. The balance was used to verify accuracy of data and procedures. As the data indicate, anisokinetic sampling produced reasonably accurate results, probably because the particle size in the stack effluent had not grown sufficiently to have a significant inertial mass. Scrubber water samples were not taken during test 1, therefore a mass balance could not be

calculated.

Moisture characteristics of the scrubber exhaust gases are presented in Table III. These data show that an increase in moisture content of the exhaust gases occurred when acid was scrubbed. This indicates that acid particle growth was occurring in the scrubber.

Individual impinger acid content is presented in Table IV. These data are included to show the efficiency of the sampling procedure. In tests 1 and 2, over 90% of the acid was collected in the first impinger. However, in test 3, just over 50% was collected in the first impinger. These data support the findings that water scrubbing in a low energy system is not as effective for perchloric acid as for nitric.

TABLE I

AAF COLAG MIST, VAPOR & FUME COLLECTOR EFFICIENCY FOR NITRIC (HNO_3) & PERCHLORIC ($HClO_4$) ACIDS

Test	Acid	Collector Operating Parameters			Acid Load		Collector Efficiency
		Water Usage ℓ/min	Air Flow M^3/min	Acid Loading+ gms/M^3	In	Out	$\frac{\text{In-Out}}{\text{In}} \times 100\%$
					gms/min		
1	HNO_3	9.6	57.79	1.19	68.8	18.1	74
2	HNO_3	9.3	57.79	3.29	189.9	47.9	75
3	$HClO_4$	9.3	57.79	0.70	40.6	15.8	61

+ Nitric & perchloric acids were boiled off in beakers - no chemical reactions occurred. The acid loading was determined in two ways; (1) measuring the volume of acid lost in a given time and (2) sampling before the scrubber. These acid loadings represent the design information given to AAF. A mass balance of acid lost from beakers and acid collected by the scrubber water plus that penetrating the scrubber is presented in Table II.

TABLE II

ACID MASS BALANCE
AAF COLAG MIST, VAPOR & FUME COLLECTOR
EFFICIENCY STUDY

Test	Acid Lost gms/min	Acid Found gms/min			Ratio Found/Lost %
		Scrubber Water	Exhaust	Total	
1	68.8	-	18.1	-	-
2	189.9	118.9	47.9	166.8	88
3	40.6	24.5	15.8	40.3	99

TABLE III

MOISTURE CHARACTERISTICS
OF
EXHAUST GASES
AAF COLAG MIST, VAPOR & FUME COLLECTOR

Test	Acid Load gms/min	Moisture Content of Exhaust Gas (%)		Increase+ %
		Room Air Thru Collector	Acid Gas Thru Collector	
1	68.8	Not measured++	1.9	-
2	189.9	1.4	2.4	1.0
3	40.6	0.7	1.7	1.0

+ Total gain in impinger weight assumed to be water mass - acid mass constituted less than 5% of weight gain in all cases.

++ During test 1 samples were taken simultaneously before and after the scrubber. The moisture content of the fume hood exhaust (prescrubber) was < 0.1%.

TABLE IV

IMPINGER ACID CONTENT
SAMPLE VOLUME
ACID LOAD
AAF COLAG COLLECTOR EFFICIENCY STUDY

Test	Impinger Acid Content mg				Sample Volume Liters	Acid Load++ mg/Liter
	1	2	3	Total		
1-A**	1282.5	11.6	0.5	1307.7*	549.28	2.38+
1-B**	184.1	6.8	0.5	192.9*	625.98	0.31
2-A	396.0	33.8	<0.1	462.7*	565.71	0.82
2-B	<0.1	<0.1	<0.1	<0.1*	397.07	0.00
3-A	10.4	6.1	5.5	30*	378.60	0.08
3-B	71.9	26.9	17.3	136.7	395.39	0.35

* Includes probe rinse acid content.

** Tests done simultaneous pre and post-scrubber. Tests 1-B, 2-A and 3-B done post-scrubber during acid scrubbing. Tests 2-B and 3-A done when no acid vapor was being generated: for baseline data.

+ Concentration in one duct - equal flow but no acid in the other duct ∴ concentration to scrubber = 1.19 mg/ℓ.

++ Out of scrubber except for 1-A. 1-A is load to scrubber.

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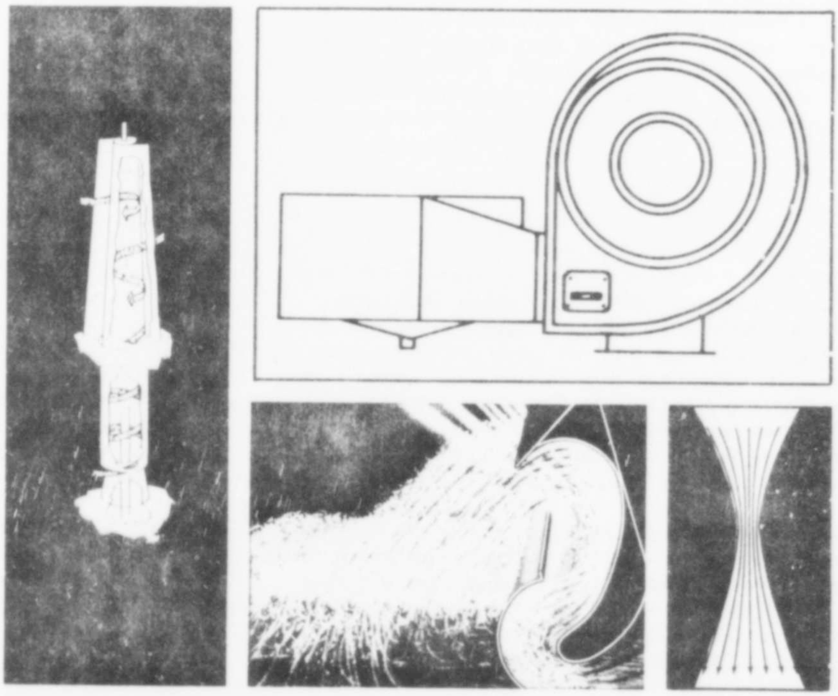
APPENDIX I

AAF WET DUST AND FUME COLLECTORS
DUST CONTROL BULLETIN NO 304

AAF WET DUST AND FUME COLLECTORS



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family of wet dust, vapor, mist, and fume collectors

American Air Filter, a pioneer in the design and development of wet dust collectors, offers the largest and most flexible line of wet dust and fume collection equipment available today. From small nuisance dust problems to large process gas cleaning applications, AAF has the **right** collector for the job — whether the contaminant is dust, fume, mist, or vapor.

AAF wet collectors have earned a reputation for quality, durability, and dependability. Equally important is the technical "know-how" of AAF engineers. This ability — gained from over 15,000 wet dust collector installations — is not limited to the selection of proper equipment type; it embraces the entire field of dust control — the entrapment of dust at its source, transportation to the collector, removal of contaminant from the air stream, and disposal of collected material.

Wet dust collectors provide a comparatively simple, low-cost solution to many dust control and air pollution problems. Space requirements are generally less than for other collector types. Because equipment size is small in relation to air cleaning capacity, most collectors can be shipped from the manufacturer completely assembled or in major sub-assemblies, simplifying installation and reducing erection costs.

Wet collectors are capable of cleaning hot, moist gases which are difficult or even impossible to handle with other collector types. Since solids are collected in a wetted form, secondary dust problems during material disposal are avoided. In addition, wet collectors are often able to eliminate or substantially reduce the hazards associated with the collection of explosive or highly flammable materials.

Wet collectors are commercially available in a wide variety of designs, shapes, and sizes. The collection principles employed are centrifugal force, impaction, and impingement, either separately or in combination.

Independent investigators studying wet collector performance have developed the Contact Power Theory, which states that for **well-designed** equipment, collection efficiency is a function of the energy consumed in the air to water contact process, and is independent of the collector design. On this basis, well-designed collectors operating at or near the same pressure drop can be expected to exhibit comparable performance.

All wet collectors have a fractional efficiency characteristic; that is, their cleaning efficiency varies directly with the size of the particle being collected. In general, collectors operating at a very low pressure loss will remove only medium to coarse-size particles. High efficiency collection of fine particles requires increased energy input, which will be reflected in higher collector pressure loss.

High-efficiency wet collection of sub-micron particulate, fume, and smoke has been made possible largely by the development of the high-energy venturi type collector. Venturi designs are now used on a large number of applications formerly limited to fabric or electrostatic collectors. In accordance with the Contact Power Theory, venturi type collectors require substantial energy input to achieve high collection efficiency on sub-micron particles.

Collector water requirements represent a continuing operating cost which must be evaluated when selecting specific equipment. When required water rates are high, substantial savings can usually be realized by using a recirculating water system. Such systems usually employ a settling tank or pond to separate the collected material by gravity. Since the water returned to the collector will invariably contain some solids, it is advantageous to choose a collector which does not require spray nozzles or other small water orifices.

Corrosive substances are often present in typical wet collector applications. Modern construction materials are capable of providing satisfactory protection against nearly all corrosive agents, but the chemical compounds present must be correctly anticipated and identified in order to make the proper material selection.

AAF engineers have the experience necessary to insure a satisfactory and successful wet collector installation. AAF can provide technical assistance in equipment selection, choosing proper materials of construction, design of recirculating water systems, or any other aspect of wet collector dust control.

For medium concentrations of fine particles

dynamic precipitator

The Type W Roto-Clone combines the scrubbing effect of water with the basic principle of dynamic precipitation — the result is a highly efficient, low-cost dust collector and air mover in one complete, shop-assembled package.

The Type W is used to collect light to medium concentrations of granular dusts, oil mists, and certain fumes. Because of its compact size and low water requirement, the Type W is often the equipment of choice when space is severely limited or water consumption must be kept to a minimum.

The Roto-Clone is designed to operate continuously at peak efficiency without interruption for reconditioning or servicing of any kind. It is ideally suited for processes requiring continuous ventilation and constant exhaust volume.

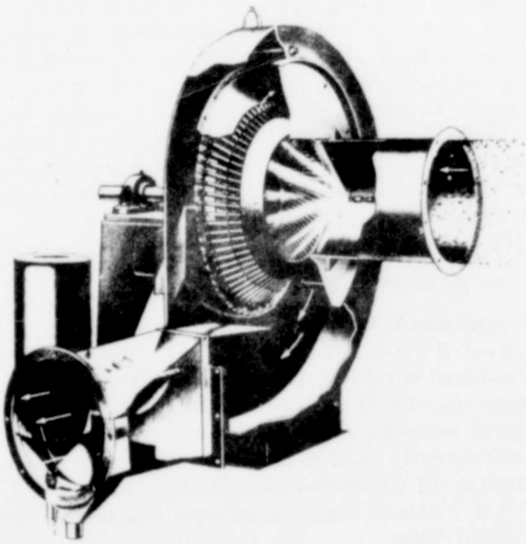
The Type W Roto-Clone is manufactured in twelve sizes with capacities ranging from 1,000 to 50,000 CFM. Water consumption is limited to the small amount required to maintain a flowing film on all collecting surfaces — normally ½ to 1 gpm per 1,000 CFM of air cleaned. The collected material is discharged in the form of a slurry. Since the Roto-Clone serves as both collector and air mover, it has no pressure drop as such. The energy input required to effect collection is reflected in a moderately lower blower efficiency.

Type W Roto-Clones can be fabricated of many materials, including stainless steels, monel, and aluminum. Corrosion resistant internal coatings are also available.

ADVANTAGES

- **Compact** — Basically no larger than a centrifugal exhauster, and as simple to install.
- **Low Water Consumption** — ½ to 1 gallon per 1,000 CFM of air cleaned on most applications.
- **Versatile** — Operating flexibility and compact size permit easy relocation to keep pace with changes in process or plant layout.
- **Economical** — Factory assembly reduces installation costs, low water requirement cuts operating cost.

REQUEST DUST CONTROL BULLETIN 274



TYPICAL APPLICATIONS

For heavy loadings of all particle size

hydrostatic precipitator

The Type N Roto-Clone is a heavy-duty orifice type collector which has established an enviable reputation for rugged dependability.

The heart of the Type N is its unique stationary impeller, where air is cleaned by the combined action of centrifugal force and thorough intermixing of air and water. Cleaning action is induced by air flow, which creates a heavy, turbulent sheet of water that traps even very fine particles. Although the required supply water rate is very low, the quantity of water in motion is quite high - approximately 20 gallons per 1,000 CFM, all of which is continuously recirculated. Simplicity of both design and operation enable the Type N to handle the toughest dust control applications.

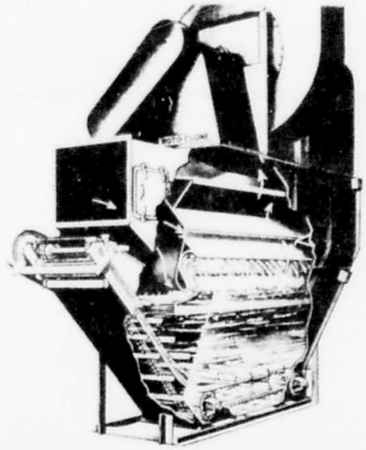
The Type N Roto-Clone is available in three basic hopper arrangements:

Arrangement B is a flat bottom design for manual removal of collected material. It is often used for the exhaust of buffing, polishing, and metalworking operations; fumes and vapors, and packaging, sorting, and weighing of chemicals and food products. It is frequently used to reclaim small to moderate quantities of valuable materials. Arrangement B is offered in eleven sizes for exhaust volumes of 750 to 32,000 CFM.

Arrangement C incorporates a drag-type sludge ejector for automatic removal of collected material. It is commonly used for abrasive cleaning and tumbling mill dust control, foundry sand systems, and for many dryer, cooler, kiln, and materials handling operations in the chemical, mining, and rock products industries. Arrangement C is available in fifteen sizes with capacity ratings ranging from 750 to 48,000 CFM.

Arrangement D utilizes a pyramidal hopper for continuous sluicing of collected material to a disposal point or back to process. Arrangement D is applied to kilns, dryers, and coolers in the chemical and rock products industries; to materials that can be periodically sluiced to process or to a disposal point; and to crushers, screens, and transfer points in the mining industry. Arrangement D can be furnished in eleven sizes for exhaust volumes of 750 to 32,000 CFM.

REQUEST DUST CONTROL BULLETIN 277



Type N Roto-Clone, Arrangement C

Collector pressure drop is 6″ w.g. at nominal capacity, and varies only slightly with fluctuations in volume handled. Extra-heavy ¼″ plate construction is available in sizes above 8,000 CFM capacity. Corrosion resistant interior construction, such as stainless steel or rubber coating, is available for all sizes and arrangements.

- **Engineered Simplicity** — Cleaning action is induced by the air flow, and water is continuously reused. No pumps, nozzles, or internal moving parts are required.
- **High Efficiency** — Cleaning action is so thorough that even very fine particles are removed from the air stream.
- **Low Water Consumption** — Requires water only slightly in excess of evaporative losses or sluicing requirements — Arr. B and C seldom require over 1 gallon per minute, excluding evaporative loss.
- **Compensating Water Level Control** — Exclusive AAF water level control maintains constant collector performance regardless of fluctuations in air volume.
- **Low Maintenance** — Designed for continuous operation with minimum service, fabricated of heavy gauge steel for long life.

Hopper Arrangements

For low cost cleaning of large exhaust volumes

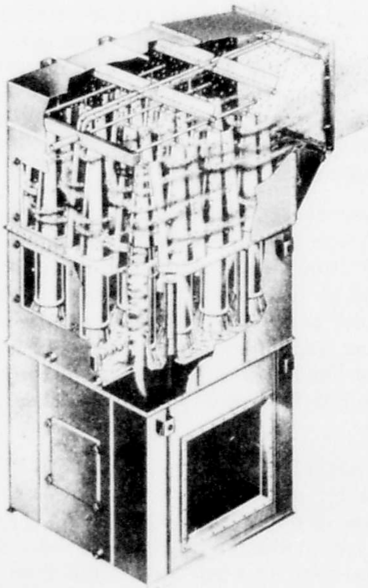
wet centrifugal dust collector

The Type R Roto-Clone utilizes a number of specially designed, double-inlet tubes to separate and trap dust particles by centrifugal force and impingement. Water introduced to each tube is carried to the periphery by high velocity dust-laden air entering the two tangential tube inlets. Centrifugal force causes dust particles to impinge against the wetted peripheral surfaces. Water and collected solids are separated from the air stream by the tube, eliminating the need for entrainment chevrons or baffles.

The Type R is used for light to heavy loadings of all size granular dusts. It is very popular for such applications as metal mining, coal handling, chemical processing, fertilizer manufacture, and foundry sand systems. Standard sizes contain from one to twenty-four tubes, each having a nominal capacity of 4500 CFM. The multiple-tube design permits great operating flexibility — tubes can be added or removed to suit changes in process or exhaust requirements. Such flexibility is extremely advantageous for installations where future expansion is planned.

Pressure loss through the Type R varies with air volume. At the nominal rating of 4500 CFM per tube, pressure drop is 5.8″ w.g. Typical water requirement is 3.5 gallons per 1,000 CFM of air cleaned. It is usual practice to recirculate water to the Type R from a settling tank or pond, adding only enough fresh water to compensate for evaporative loss. Since there are no spray nozzles or small orifices to plug, the Type R can use water having high solids content.

Standard Type R Roto-Clones have 10 gauge HRS housings and Type 304 stainless steel tubes. Optional construction materials include ¼″ plate, all stainless steel, monel, and internal protective coatings.

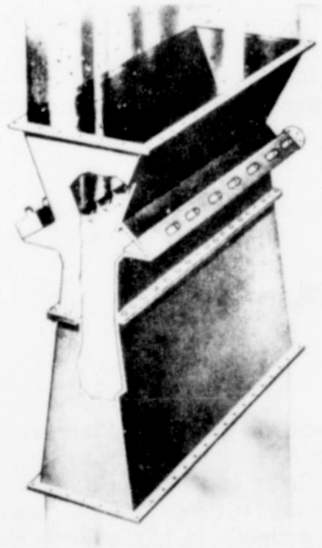


- No moving parts
- No entrainment eliminators
- No water in suspension
- No spray nozzles
- Small space requirement
- Light weight
- Flexibility in arrangement
- Wide range of capacities

Acid pickling
Brake shoe grinding
Chemical processing
Coal handling
Fertilizer dryers and coolers
Food products
Foundry sand systems
Lead battery plants
Lightweight aggregate kilns
Metal mining
Municipal incinerators
Ore pelletizing plants
Paper dust
Pharmaceuticals
Sandblasting
Sugar granulators

REQUEST DUST CONTROL BULLETIN 293

For ultra-high cleaning efficiency



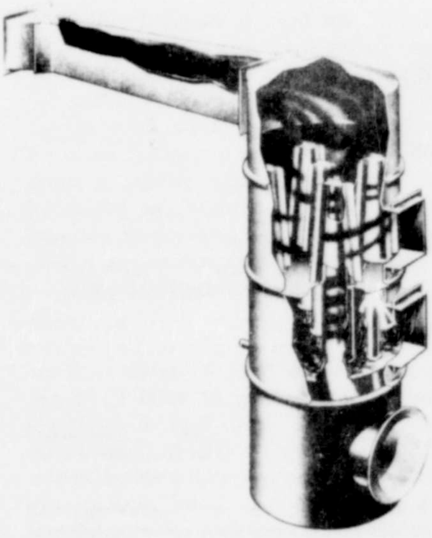
kinetic scrubber

The AAF Kinpactor utilizes kinetic energy to collect very small dust and fume particles by the principle of impaction. The contaminated gas stream is accelerated to high velocity in the venturi shaped throat section — water introduced to the throat is atomized by the high velocity gas, and the contaminant particles collide with and are trapped by millions of small water droplets. The gas stream is decelerated - and maximum static pressure regained - in the long diverging section behind the Kinpactor throat. Entrained water droplets are removed from the gas stream by a Type R Separator or cyclonic separator.

Gas-water contact is so thorough that even submicron particles are removed. The degree of cleaning is a direct function of energy input, which is reflected by the pressure drop across the Kinpactor. Throat pressure drop ranges from 8" w.g. to 100" w.g. depending on the contaminant particle size and desired degree of cleaning. Usual water requirement is 8 gallons per 1000 CFM of gas cleaned.

The Kinpactor may be equipped with either a Type R Separator or a Cyclonic Separator. The Type R Separator is a modification of AAF's Type R Roto-Clone dust collector. It requires less space and provides more positive separation than any other centrifugal type eliminator. If the collected material is cementacious or extremely sticky, a cyclonic separator is recommended for ease of service.

Kinpactors and separators can be fabricated of mild steel, stainless steel, rubber-lined steel, monel, and fiberglass-reinforced polyester.



For Iron and Steel
Cupolas
Blast furnaces
Basic oxygen furnaces
Open hearth furnaces
Electric arc furnaces
Scarfing machines
Sintering machines

For Chemical Process
Fertilizer dryers and coolers
Fertilizer ammoniators
Acid concentrators
Spray dryers
Flash dryers
Roasting kilns

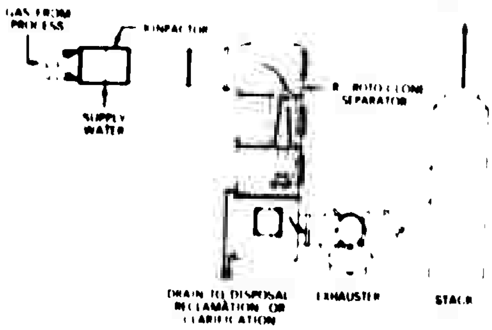
For Pulp and Paper
Lime kilns
Black liquor recovery boilers

For Non-Ferrous Metals
Aluminum furnaces
Lead blast furnaces
Reverbatory furnaces
Induction furnaces
Sintering

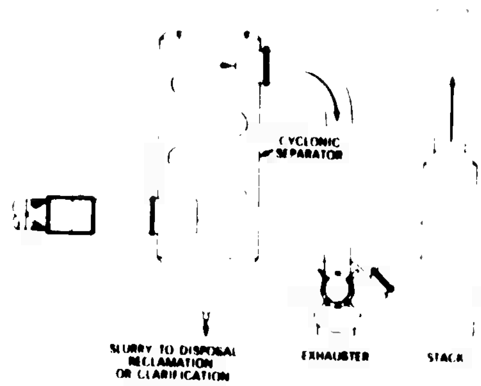
For Other Processes
Asphalt plants
Coal processing
Salt bath paint stripping
Incinerators
Boiler flue gas
Wire insulation burning
Galvanizing kettles
Plastic and resin fumes

REQUEST DUST CONTROL BULLETIN 294

Kinpactor-separator arrangements



Typical Arrangement with Roto-Clone Separator



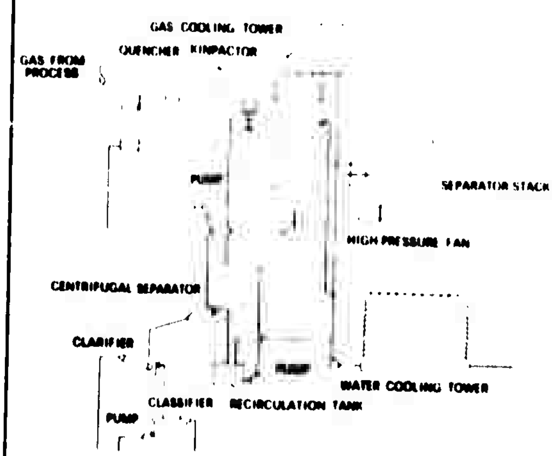
Typical Arrangement with Cyclonic Separator

AAF designs and manufactures custom-engineered kinetic scrubber systems for larger volume process gas applications. Custom systems are normally used to clean hot gas volumes above 50,000 CFM. Kinetic scrubber systems commonly include:

- Quencher to initially cool process gas
- Kinpactor kinetic scrubber
- Gas cooling tower to further cool cleaned gas and recover the water evaporated in the quencher and Kinpactor
- High pressure fan
- Separator to remove any entrained water droplets
- Water cooling tower to remove heat absorbed from the gas stream
- Water recirculation system to remove collected solids from the effluent slurry and return clean water to the scrubber

Systems can be designed to reduce exit dust concentration to 0.05 grains per cubic foot or less. The Kinpactor can be equipped with an automatically controlled variable throat damper which maintains the same high cleaning efficiency regardless of fluctuations in process gas volume.

AAF offers complete turnkey design and installation of the entire kinetic scrubber air pollution control system.



Typical custom-designed Kinpactor kinetic scrubber system.

REQUEST PAD BULLETINS 205 AND 206

For chemical fumes, mist, and vapor

fume scrubber

The unique COLAG fume scrubber is the result of AAF's search for a better means to collect chemical fumes, mists, and vapors.

The COLAG uses a specially designed scrubbing pad arrangement to thoroughly clean the contaminated air. Air enters the unit at high velocity and is evenly distributed by a special perforated plate. The reaction pad, located just above the plate, is constantly saturated with water to create millions of flooded, bubbling contact surfaces which scrub and re-scrub the air. Liquid droplets which pass from the reaction pad are trapped by sloped eliminator pads.

The COLAG is ideal for the collection of inorganic and organic acids, alkalies, water-soluble solvents, halogens, and ammonia. Because of its high collection efficiency and low water rate, the COLAG acts as an excellent concentrator and is often utilized as an important part of a process system.

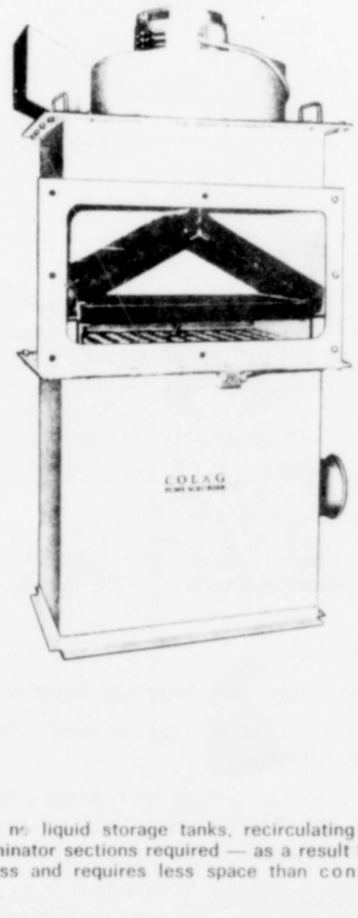
The COLAG is available in seven sizes for air volumes of 1150 to 25,000 CFM. Arrangements utilizing one, two or three collection stages can be furnished. Units can be fabricated of mild steel, stainless steel, monel, solid PVC, and fiberglass-reinforced polyester. Protective coatings are also available.

Operation and maintenance is simplified by a large plexiglass observation window which provides easy access to the pads and plate. Disposable type pads slide out of the observation window for quick, low-cost replacement.

Highest Efficiency — The collection efficiency of the COLAG cannot be exceeded by any other fume scrubber operating at a comparable pressure loss and water rate.

Lowest Water Usage — The unique design of the COLAG allows operation at a lower water rate than any other collector of this type — as low as 0.1 gallons per 1,000 CFM of air cleaned.

Smallest Size — The COLAG operates at a substantially higher air velocity than other packing-type scrubbers.



There are no liquid storage tanks, recirculating pumps, or heavy eliminator sections required — as a result the COLAG weighs less and requires less space than conventional collectors.

TYPICAL APPLICATIONS

- Aluminum anodizing
- Pickling
- Electroplating
- Coating stripping
- Acid dipping
- Metal cleaning
- Electro-polishing
- Metal etching
- Metal surface treatment
- Printed circuit etching
- Lab hood exhaust

Collector performance is usually stated in terms of collector efficiency, which may be calculated by the equation

$$\text{Efficiency } (\%) = \frac{M_I - M_O}{M_I} \times 100$$

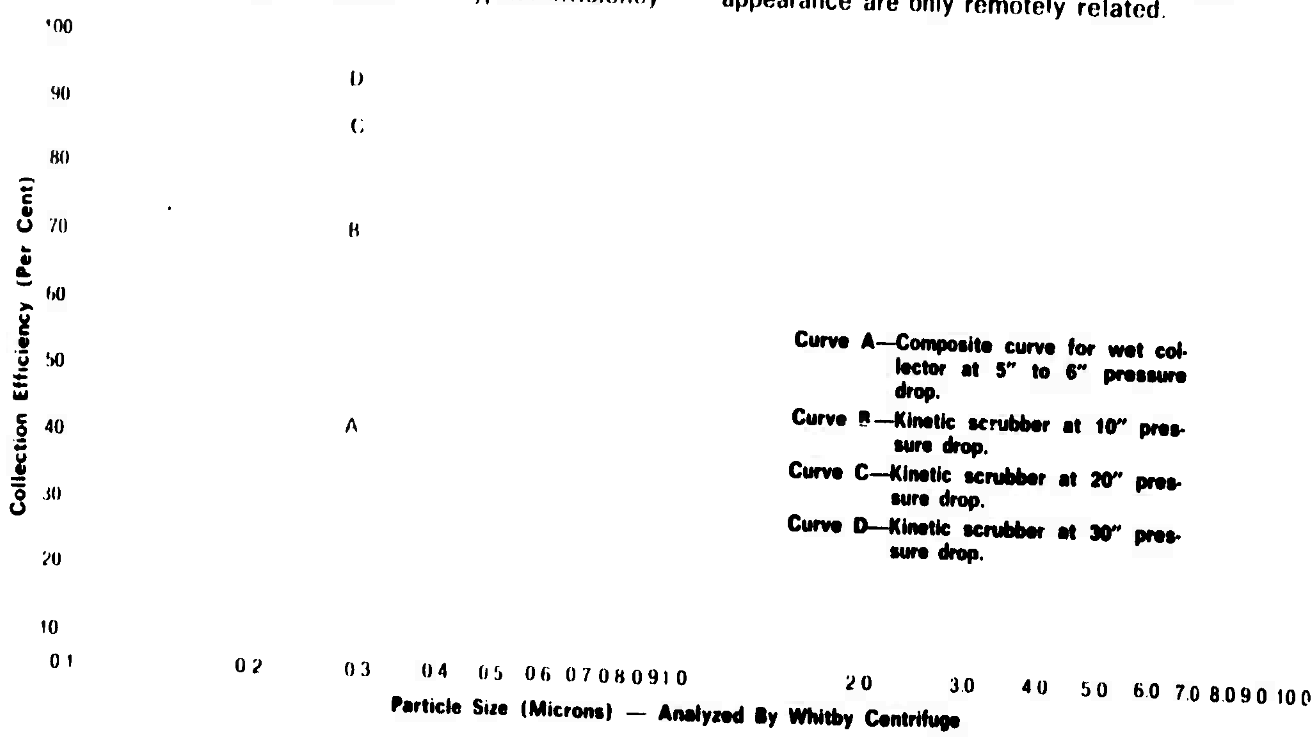
where M_I is the contaminant mass flow rate at the collector inlet and M_O is the contaminant mass flow rate at the collector outlet. Air pollution regulations normally establish the allowable rate of contaminant emission. Where no regulation exists, the user must determine the desired exit level, possibly by referring to regulations in nearby locales. The value of M_I is fixed by the application, and can be determined accurately by isokinetic sampling of the gas stream. If the process is not yet in operation, M_I can be estimated on the basis of test data from similar applications.

Because wet collectors have a fractional efficiency characteristic, the stated efficiency for a given collector is only meaningful when it is based on particle size, usually expressed in microns. There are many ways of determining particle size, and the results vary widely — one method might indicate a particle diameter of 5 microns while a second method could give a value as low as 3 microns. It should be readily apparent that collector efficiency curves can be misleading if the method of particle size analysis is not stated.

In accordance with the Contact Power Theory (see page 2), Curve **A** represents the typical efficiency of any well designed wet collector operating at a 5 to 6″ w.g. pressure drop, when particle size is determined by the Whitby Centrifuge (liquid-sedimentation) method. Published curves for such collectors may deviate appreciably from the curve shown. When appropriate corrections are made to compensate for the method of particle size analysis, the deviations will almost invariably disappear and the curves found to coincide.

Curves **B, C,** and **D** show collection efficiency vs particle size for a kinetic scrubber operating at pressure drops of 10″, 20″, and 30″ w.g., respectively. Efficiency is substantially higher in the small particle size range due to the additional energy expended to improve air-water contact.

The fractional efficiency characteristic of wet collectors presents an additional problem in evaluating performance. Efficiency is commonly expressed on a weight basis. An efficiency of 98 to 99 per cent by weight **does not** necessarily ensure that the contaminant discharged to atmosphere will not be visible. Visibility is a function of light reflectance, which in turn is directly proportional to the surface or reflective area of the particles emitted. Since a unit weight of small particles represents considerably more total surface area than an equal weight of large particles, it is entirely possible to collect over 90% of the particles by weight (by capturing the larger sizes) yet remove less than 30% of the total reflective area. It should be kept in mind that collection efficiency and discharge appearance are only remotely related.



OPERATION	Dust Loading	Particle Size	Type W Roto Clone	Type N Roto-Clone	Type R Roto-Clone	Kinpactor	Notes
CERAMICS							
Materials Handling	Light	Fine	USUAL	Frequent	Frequent	Not Req'd	1
Fettling and Grinding	Med Hvy	Fine Med	Occasional	Frequent	Frequent	Not Req'd	2
Spraying	Lt Med	Medium	USUAL	Occasional	Occasional	Not Req'd	
CHEMICALS							
Materials Handling	Lt Hvy	Varies	Frequent	USUAL	USUAL	Rare	3, 4
Crushing and Grinding	Med Hvy	Varies	Occasional	USUAL	USUAL	Occasional	4
Weighing and Screening	Lt Mod	Fine Med	USUAL	Frequent	Frequent	Not Req'd	4
Roasters Kilns Dryers	Heavy	Medium	Occasional	USUAL	USUAL	Frequent	4, 5, 6
Bin Ventilation	Light	Fine Med	USUAL	Occasional	Occasional	No	
FERTILIZER							
Screening and Handling	Med Hvy	Fine Med	Occasional	No	No	No	
Dryer Cooler	Heavy	Fine Med	Occasional	Occasional	Occasional	USUAL	5
Ammoniator	Lt Med	Fine	Rare	No	Rare	USUAL	5
COAL MINING AND POWER PLANT							
Materials Handling	Moderate	Medium	Frequent	USUAL	USUAL	Not Req'd	
Bunker Ventilation	Light	Fine	Frequent	Rare	Rare	Not Req'd	7
Dedusting and Cleaning	Heavy	Medium	Frequent	USUAL	USUAL	Not Req'd	
Dryers	Heavy	Fine Medium	No	Frequent	USUAL	USUAL	5
FOUNDRY							
Abrasive Cleaning	Mod Hvy	Fine Med	No	Occasional	Rare	Not Req'd	6
Shakeout Enclosed Hood	Moderate	Fine	Rare	Frequent	USUAL	Rare	
Shakeout Side Hood	Light	Fine	USUAL	Rare	USUAL	Rare	
Sand Handling	Moderate	Fine Med	Rare	Frequent	USUAL	Not Req'd	
Tumbling Mills	Heavy	Medium	Rare	USUAL	No	No	6
Cupola	Moderate	Varies	No	No	No	USUAL	5, 6, 8
Non Ferrous Melting	Varies	Ext Fine	No	Occasional	No	USUAL	5, 6
PHARMACEUTICALS AND FOOD PRODUCTS							
Mixing, Grinding, Weighing, Blending Packaging	Light	Medium	USUAL	Frequent	Frequent	Not Req'd	6
Coating Pans	Varies	Fine Med	USUAL	No	Frequent	No	
Sugar Handling	Light	Fine Med	Frequent	Occasional	Frequent	Not Req'd	6
Sugar Granulators	Moderate	Fine Med	USUAL	Frequent	Frequent	Not Req'd	
ROCK PRODUCTS AND METAL MINING							
Materials Handling	Mod Hvy	Fine Med	Occasional	USUAL	USUAL	Not Req'd	6
Crushing and Screening	Heavy	Medium	Occasional	USUAL	USUAL	Rare	6
Dryers and Kilns	Mod Hvy	Fine Med	Rare	USUAL	USUAL	USUAL	5, 6
Coolers	Moderate	Coarse	Rare	Occasional	Occasional	Not Req'd	

NOTES:

1 Dust released from bin filling, weighing, mixing, pressing, and forming. Refractory products screening and dry pan operations more severe
2 Operations found in vitreous enameling, wall and floor tile, and pottery
3 Includes conveying, elevating, mixing, and packaging.
4 Category covers so many different materials that specific recommendations are difficult to report
5 Corrosion protection normally required.

OPERATION	Dust Loading	Particle Size	Type W Roto-Clone	Type N Roto-Clone	Type R Roto-Clone	Kinpactor	Notes
RUBBER AND PLASTIC PRODUCTS							
Mixers	Moderate	Fine	Frequent	Occasional	Occasional	Not Req'd	6
Batchout Rolls	Light	Fine	USUAL	Rare	Rare	No	6
Talc Dusting	Moderate	Medium	Frequent	Occasional	Occasional	Not Req'd	6
Grinding and Buffing	Moderate	Coarse	Frequent	Occasional	No	Not Req'd	
Plastics M'l'l Handling	Moderate	Medium	USUAL	Frequent	Occasional	Not Req'd	
Plastics Finishing	Light	Fine Med	Occasional	Occasional	Occasional	Not Req'd	
STEEL MILLS							
Basic Oxygen Furnace	Med Hvy	Ext Fine	No	No	No	USUAL	5, 6
Electric Arc Furnace	Light	Ext Fine	No	No	No	Frequent	5, 6, 9
Open Hearth	Med Hvy	Fine	No	No	No	USUAL	5, 6
Blast Furnace	Heavy	Varies	No	No	No	USUAL	5, 6
Scarfing	Light	Ext Fine	No	Rare	No	USUAL	
Coal and Coke Handling	Moderate	Medium	Frequent	USUAL	USUAL	Not Req'd	
Sintering Machines							
Bed Exhaust	Medium	Fine Med	No	Rare	No	Rare	5
End Dump Screen	Heavy	Fine Med	No	USUAL	Rare	Frequent	
Hot Strip Mills	Light	Fine	No	USUAL	Rare	Frequent	
Coke Screening	Med Hvy	Medium	Rare	Occasional	Occasional	Not Req'd	6
Materials Handling	Med Hvy	Fine Med	Rare	Rare	Frequent	Occasional	6
MISCELLANEOUS							
Acid Mists	Light	Fine	Frequent	Frequent	Occasional	[illegible]	5, 10
Acid Pickling	Moderate	Fine	Rare	USUAL	USUAL	Occasional	5
Asphalt Plant Dryers	Heavy	Fine Med	No	Frequent	Frequent	USUAL	5
Brake Lining Grinding & Sanding	Heavy	Medium	Frequent	Rare	Frequent	Not Req'd	
Lead Battery Plants	Light	Fine Med	Occasional	USUAL	Frequent	Occasional	5
Leather Buffing	Moderate	Medium	USUAL	No	Occasional	Not Req'd	
Leather Sanding	Moderate	Fine Med	Frequent	No	Frequent	Not Req'd	
Metal Buffing and Polishing	Light	Varies	No	USUAL	No	No	
Newspaper Lead Pots	Light	Fine	USUAL	Rare	No	No	
Offset Spray	Light	Fine	USUAL	Rare	Occasional	Not Req'd	
Paint Stripping (Salt Bath)	Light	Ext Fine	No	No	No	USUAL	
Paper Cutting	Moderate	Medium	Occasional	No	No	No	
Paper Grinding	Mod Hvy	Medium	Occasional	Rare	No	No	
Wood Sanding	Moderate	Fine	Frequent	No	No	No	

6 Fabric collectors (AAF AMERtube, AMERpulse, AMERtherm) are frequently used.
7 High efficiency dry centrifugal collectors (AAF Type D Roto-Clone) frequently used.
8 AAF AMERclone high efficiency dry centrifugal can be used where codes permit 0.20 grains per cubic foot in discharge and #2 Ringleman opacity.
9 Many furnaces now use direct shell evacuation instead of old style hood.
10 AAF COLAG fume scrubber frequently used.

The listings under "Dust Loading" and "Particle Size" are averages and will vary from job to job. The ranges are as follows.

Dust Loading		Particle Size	
Light	½ to 2 Grains/Cu Ft	Extremely Fine	50% in ½ to 2 Micron Range
Medium	2 to 3 Grains/Cu Ft	Fine	50% in 2 to 7 Micron Range
Moderate	3 to 5 Grains/Cu Ft	Medium	50% in 7 to 15 Micron Range
Heavy	Over 5 Grains/Cu Ft	Coarse	50% Above 15 Microns

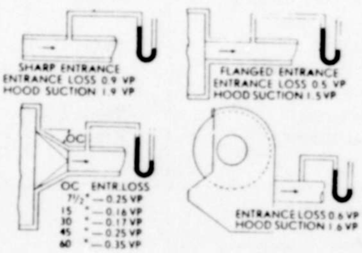
TABLE 1		TABLE 2	
Area of Circles		Velocity Pressure	
Dia	Sq. Ft	WG	FPM
1½	.0123	.10	1266
2	.0218	.15	1550
2½	.0341	.20	1791
3	.0491	.25	2003
3½	.0668	.30	2193
4	.0873	.35	2373
4½	.1104	.40	2533
5	.1364	.45	2688
5½	.1650	.50	2832
6	.1964	.55	2973
6½	.2304	.60	3102
7	.2673	.65	3230
7½	.3068	.70	3351
8	.3491	.75	3468
8½	.3942	.80	3582
9	.4418	.85	3692
9½	.4923	.90	3800
10	.5454	.95	3905
11	.6600	1.00	4005
12	.7854	1.10	4208
13	.9218	1.20	4390
14	1.069	1.30	4566
15	1.227	1.40	4735
16	1.396	1.50	4905
17	1.576	1.60	5065
18	1.767	1.70	5225
19	1.969	1.80	5380
20	2.182	1.90	5522
21	2.405	2.00	5664
22	2.640	2.20	5940
23	2.885	2.40	6210
24	3.142	2.50	6340
25	3.409	2.60	6460
26	3.687	2.80	6700
27	3.976	3.00	6937
28	4.276	3.20	7170
29	4.587	3.40	7390
30	4.909	3.50	7500
32	5.585	3.60	7610
33	5.940	3.80	7810
34	6.305	4.00	8010
36	7.069	4.20	8210
38	7.876	4.40	8400
40	8.727	4.50	8490
42	9.621	4.60	8590
45	11.045	4.80	8770
48	12.566	5.00	8950

TABLE 3 Temperature—Density		
Temp °F	Density Factor	Wt. Per Cu. Ft.
0	1.152	.0864
70	1.000	.0749
100	.946	.0709
150	.869	.0651
200	.803	.0602
250	.747	.0560
300	.697	.0522
350	.654	.0490
400	.616	.0462
450	.582	.0436
500	.552	.0414
550	.525	.0393
600	.500	.0375
650	.477	.0358
700	.457	.0342
750	.438	.0328
800	.421	.0315
850	.404	.0303
900	.390	.0292
950	.376	.0282
1000	.363	.0272

TABLE 4 Altitude—Density		
Elev. In Ft.	Density Factor	Wt. Per Cu. Ft.
0	1.000	.0749
500	.981	.0735
1000	.962	.0721
1500	.944	.0707
2000	.926	.0694
2500	.909	.0681
3000	.891	.0668
3500	.874	.0655
4000	.858	.0643
4500	.842	.0631
5000	.826	.0619
5500	.810	.0607
6000	.795	.0596
6500	.780	.0585
7000	.766	.0574
7500	.751	.0563
8000	.737	.0552
8500	.723	.0542
9000	.710	.0532
9500	.697	.0522
10000	.685	.0514

TABLE 5—AIR VOLUME IN CFM HANDLED THROUGH BRANCH PIPES										
Diameter of Pipe	Velocity in Pipe in FPM									
	2000	2500	3000	3500	3750	4000	4500	5000	5500	6000
3"	98	123	147	172	184	197	221	246	270	295
3½"	134	167	200	204	250	267	300	334	367	400
4"	175	218	262	306	327	350	393	437	480	524
4½"	221	276	331	387	415	442	497	552	608	663
5"	273	341	409	478	512	546	614	682	750	818
5½"	330	413	495	578	618	660	742	825	908	990
6"	393	491	589	688	736	786	884	982	1080	1178
7"	534	668	802	936	1002	1070	1204	1338	1472	1605
8"	699	874	1048	1220	1309	1396	1571	1745	1920	2095
9"	882	1105	1325	1546	1652	1766	1988	2210	2430	2650
10"	1092	1364	1637	1910	2046	2182	2456	2730	3000	3273
11"	1320	1650	1980	2310	2475	2640	2970	3300	3630	3960
12"	1570	1965	2355	2750	2946	3140	3535	3915	4320	4712
13"	1840	2305	2765	3225	3457	3685	4150	4610	5057	5531
Entr. Loss In VP	TABLE 6—SUCTION IN INCH W.G. FOR VARIOUS ENTRANCE LOSSES (Suction Equals 1 VP + Entrance Loss)									
0.2	0.30	0.47	0.67	0.92	1.06	1.20	1.52	1.87	2.27	2.70
0.4	0.35	0.55	0.79	1.08	1.23	1.40	1.77	2.18	2.64	3.15
0.6	0.40	0.62	0.90	1.22	1.41	1.60	2.02	2.50	3.02	3.60
0.8	0.45	0.70	1.01	1.39	1.58	1.80	2.28	2.81	3.40	4.05
1.0	0.50	0.78	1.12	1.54	1.76	2.00	2.53	3.12	3.78	4.50
2.0	0.75	1.17	1.68	2.31	2.64	3.00	3.80	4.68	5.67	6.75

TABLE 7—Equivalent Resistance of Elbows and Branch Entries (In Feet of Straight Pipe)					
Dia. of Pipe	90° Elbow Inside Radius			Angle of Entry	
	1 D	1½ D	2 D	30°	45°
3"	5	4	3	2	3
4"	7	5	4	3	5
5"	9	6	5	4	6
6"	11	7	6	5	7
7"	13	9	7	6	9
8"	14	10	8	7	11
10"	20	13	11	7	14
12"	25	17	14	11	17
14"	30	21	17	13	21
16"	36	24	20	16	25
18"	41	28	23	18	28
20"	46	32	26	20	32
24"	57	38	32		
30"	75	51	42		
36"	87	60	49		
For 60° El. × .75					
For 45° El. × .50					



PIPE RESISTANCE CHART